Association of High Fat Diet with Bone Mineral Density in the General American Population

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Research Article

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Abstract

Background

The effect of a high-fat diet on bone mineral density is still controversial. The present study is to evaluate the relationship between a high-fat diet and bone mineral density in the American adults.

Methods

We performed a cross-sectional analysis of the US population aged 50 years or older based on data from the National Health and Nutrition Examination Survey (NHANES) 2017-2018. The primary outcome measure was the femur bone mineral density by dual energy x-ray absorptiometry (DXA) of osteoporosis or osteopenia. Multivariable logistic regression analysis was used to evaluate the effect of high-fat diet on the presence of osteopenia and osteoporosis.

Results

The prevalence of total femur, femoral neck, trochanter and intertrochanter osteopenia or osteoporosis respectively was 22.8%, 51.3%, 22.6% and 19.4% in men and 43.5%, 66.9%, 39% and 38% in women. Multivariable logistic regression analysis after adjustment for confounders showed that a high-fat diet was significantly associated with higher odds of total femur and trochanter osteopenia or osteoporosis in men and intertrochanteric osteopenia or osteoporosis in women. However, a high-fat diet was negatively associated with the occurrence of osteopenia or osteoporosis in male femoral neck and total femur and femoral neck in female. There were no significant associations between high-fat diet and osteopenia or osteoporosis in male intertrochanteric and in female trochanter. The subgroup analyses found that compared with normal fat intake, the highest fat intake levels were only significantly and negatively associated with femoral neck osteopenia or osteoporosis in men and total femur, trochanter and intertrochanteric in women.

Conclusions

The effects of a high-fat diet as a separate contribution to the incidence of osteopenia or osteoporosis were biphasic with both positive and negative effects that varied by femoral sites and were not gender-related. In addition, higher levels of dietary fat intake did not increase subject's the odds of osteopenia or osteoporosis.

Background

Osteoporosis, as a systemic skeletal disease, is characterized by decreased bone mass, microstructural deterioration of bone tissue, and weakened bone strength, leading to increased skeletal fragility and fracture susceptibility[1]. Osteoporosis and osteoporotic fractures are widely prevalent in postmenopausal women and male senior over the age of 50 years[2, 3]. Studies show that worldwide, the annual cost of treating osteoporosis-related fractures is comparable to or greater than the cost of treating
many other serious chronic conditions[4, 5]. Severe osteoporosis and osteoporotic fractures, with significant morbidity, disability and mortality, have evolved into a social and family burden, and that the burden will increase significantly in the future[4, 6]. Furthermore, osteoporosis or osteopenia is considered to be an underdiagnosed disease that poses a hidden trouble for the prevention and treatment of osteoporotic fractures[7].

The diagnosis of osteoporosis and osteopenia is based on the T score of bone mineral density (BMD). Hip fracture is considered as a typical osteoporotic fracture, which is closely related to the decrease of BMD at hip[8]. Among the numerous risk factors for osteoporosis such as age, gender, body weight, estrogen, genetic factors, smoking, alcohol consumption, environmental and various metabolic diseases, low BMD is of utmost importance[9]. Bone mass begins to decrease with age after peak bone mass in adults, and bone health is also affected by dietary macronutrient intake[10, 11]. Overwhelming evidence indicates that a high-fat diet that can affect bone mass, bone microarchitecture and impair bone metabolism (bone growth and bone loss)[12–14]. Meanwhile, there is a traditional consensus that an increasingly common high-fat diet results in lower BMD, leading to the prevalence of osteoporosis and osteoporotic fractures[13]. This perspective that higher fat intake reduces bone mineral density and bone strength was also confirmed in a Korean population study[15]. However, the effects of a high-fat diet on bone health are complex, and other studies have found a positive effect of a high-fat diet on bone mineral density[12, 16–18].

Therefore, the purpose of this study was to obtain evidence from the general population of the United States of a possible association between a high-fat diet and BMD (as assessed by DXA) in men and women 50 years of age and older.

**Methods**

**Study Participants**

All data from the US National Health and Nutrition Examination Survey (NHANES) 2017–2018. The NHANES is a program of studies conducted by the Centers for Disease Control and Prevention (CDC) that focuses on a variety of health and nutrition measures in the U.S. population. A total of 3069 adults aged 50 years or older were included. Then, those who were not examined in the mobile examination center (MEC) (n = 171) and DXA (n = 612) were removed. Based on participants from two 24-hour dietary recall interviews, we excluded those without qualified dietary recall status and missing data. In calculating macronutrients distribution and energy intake, participants were included if they answered “Usual” to the question “Was the amount of food that you ate yesterday much more than usual, usual, or much less than usual?” The final number of participants enrolled in this study was 1131 (Fig. 1). Given that the datasets in all analyses were fully de-identified, this study was approved by the Institutional Review Board.
Clinical And Laboratory Data Collection

We collected some relevant data on demographic, body measures, laboratories, and questionnaire. Demographic variables including gender (Male, Female), age, race/Hispanic origin (Mexican American, Other Hispanic, Non-Hispanic White, Non-Hispanic Black, and Other Race) and marital status (Married/Living with partner; Widowed/Divorced/Separated, /Never married). Smoking - cigarette use and alcohol use were ascertained by questionnaire. Participants who answered to “Yes” to the question “Smoked at least 100 cigarettes in entire life?” were considered smoking status. Similarly, people who answered to “Yes” to the question “Ever had a drink of any kind of alcohol?” were considered drinking status. Body measures data included waist circumference, hip circumference and body mass index (BMI), which was calculated as weight in kilograms divided by height in meters squared. Abdominal obesity was defined as waist circumference > 102 cm for men and > 88 cm for women[19]. Laboratory indicators included high density lipoprotein-cholesterol (HDL-C), low density lipoprotein-cholesterol (LDL-C), total cholesterol, 25-hydroxyvitamin D3 (25-OHD3), total calcium, blood cadmium and high sensitivity c-reactive protein (HS-CRP). The three consecutive blood pressure (BP) measurements were averaged as the BP of the participants. Hypertension was defined by systolic blood pressure ≥ 140 mmHg and/or diastolic blood pressure ≥ 90 mmHg or currently taking prescribed medicines for hypertension[20]. Diabetes mellitus was defined as satisfying any of the following conditions: 1) self-reported diabetes; 2) use of antidiabetic drugs; 3) fasting plasma glucose ≥ 126mg/dL; 4) glycated hemoglobin (HBA1c) level ≥ 6.5%; 5) random plasma glucose concentration ≥ 200 mg/dL[21]. Family history of osteoporosis was classified according to the question “Parents ever told had osteoporosis?”.

Bone Mineral Density Measurement

The femur scans by DXA provide BMD (gm/cm$^2$) for the total femur, femoral neck, trochanter and intertrochanter. The left hip was routinely scanned unless the participant self-reported a left hip fracture, replacement, or a pin in the left hip. The right hip was scanned in this situation. Participants were excluded from the DXA examination if: 1) pregnancy (positive urine pregnancy test and/or self-report at the time of the DXA examination); 2) self-reported history of radiographic contrast material, such as dyes or barium, in the past 7 days; 3) measured weight over 450 pounds (DXA table limitation); 4) had fractured both hips, had replacements of both hips, or had pins in both hips. According to the guidelines of the World Health Organization (WHO), the diagnostic criteria of osteoporosis or osteopenia are defined using T-scores[22]. Osteopenia was defined as $2.5 < T$-score $< -1$ and osteoporosis as a $T$-score $\leq -2.5$. T-scores were calculated as (BMD respondent − mean BMD reference)/SD reference. The reference subjects for calculation of hip T-scores were generally non-Hispanic white women aged 20–29 years from NHANES III[23].

Dietary Intake Assessment
All participants conducted two 24-hour dietary recall interviews. The first dietary recall interview was collected in-person in the MEC and the second interview was collected by telephone 3 to 10 days later. For each participant, the total nutrient intakes files for the first day and second day provide information on daily total energy and nutrient intakes from food and beverages, and whether the amount of food consumed was usual, much more or much less than usual. Data for total energy intake (kcal/day) and macronutrients composed of protein (g/day), carbohydrates (g/day) and total fat (g/day) were extracted from total nutrients intakes files. Total energy intake is the sum of energy from protein, carbohydrate, total fat, and alcohol, consumed during the previous 24-hour period. Intake of macronutrients, expressed as a percentage of total energy intake, converts grams of macronutrients to kcals according to the following criteria: 4 kcals/gram for protein and carbohydrate, and 9 kcals/gram for total fat[24, 25]. Participants were categorized into two groups by the total fat intake as a percentage of total energy intake (%E): normal-fat diet ≤ 35%E; high-fat diet > 35%E. The classification criteria of high-fat diet referred to the daily nutritional goals of people ≥ 50 years old recommended by Dietary Guidelines for Americans 2015–2020 Eighth Edition[26].

**Statistical Analysis**

All analyses were performed using Stata version 17.0. We applied appropriate sample weights to all analyses, as suggested by the National Center for Health Statistics (NCHS). Categoric variables were expressed as weighted proportions ± standard error (SE). Continuous variables were expressed as weighted means ± SE or median (interquartile range) if non-normal distribution. The characteristics of participants with high-fat diet and normal-fat diet status were compared using t-test for continuous variables or Kruskal–Wallis test if non-normal distribution and chi-square test for categorical variables. Multivariable logistic regression analysis was used to evaluate the effect of high-fat diet on the presence of osteopenia and osteoporosis after adjustment for confounders. Male and female were analyzed separately. A 2-tailed P value < 0.05 was considered statistically significant. The covariates with missing data were subjected to multiple imputation. Multicollinearity was tested by calculating the variance inflation factor before adjustment. The subgroup analyses were stratified by high-fat diet as follows: I 35% < total fat intake ≤ 40%E; II 40% < total fat intake ≤ 45%E; III 45% < total fat intake ≤ 50%E; IV total fat intake > 50%E.

**Results**

Weighted prevalence of high-fat diet was 59.5% (95%CI, 52.7% – 66%) and 54% (95%CI, 46.5% – 61.3%) among the 614 males and 517 females included in the study, respectively. Total femur osteopenia or osteoporosis occurred in 22.8% (95%CI, 17.8% – 28.7%) of males and 43.5% (95%CI, 36.3% – 50.9%) of females. Femoral neck osteopenia or osteoporosis occurred in 51.3% (95%CI, 44.3% – 58.2%) of males and 66.9% (95%CI, 59.7% – 73.4%) of females. Trochanter osteopenia or osteoporosis occurred in 22.6% (95%CI, 17.6% – 28.5%) of males and 39% (95%CI, 32.1% – 46.4%) of females. Intertrochanter osteopenia or osteoporosis occurred in 19.4% (95%CI, 14.6% – 25.3%) of males and 38% (95%CI, 31% – 45.4%) of females.
Table 1 displayed the baseline characteristics of participants on a high-fat diet and normal-fat diet. In both sexes, participants in a high-fat diet tended to be non-Hispanic and had higher levels of BMI, waist and hip circumference and HDL-C. They also presented a higher incidence of abdominal obesity. Men on a high-fat diet were older, drank less, and had no significant difference in smoking. By contrast, women on a high-fat diet, though not different in age, preferred drinking and smoking. No significant differences were presented in married status and levels of LDL-C, total cholesterol, triglyceride, 25-OHD3, total calcium, blood cadmium, and HS-CRP in both sexes. There was also no difference in the prevalence of hypertension, diabetes and family history of osteoporosis. As far as the DXA examination is concerned, women with a high-fat diet had higher BMD and lower prevalence of osteopenia or osteoporosis in femoral neck and trochanter, but had no significant effects on BMD osteopenia or osteoporosis of total femur and intertrochanteric. For male participants, the high-fat diet did not contribute to BMD and osteopenia or osteoporosis in total femur, femoral neck, trochanter and intertrochanteric.

Multivariable logistic regression analysis was carried out to explore the independent contribution of high-fat diet to the incidence of osteopenia or osteoporosis. The result of all analyses was shown in Fig. 2 and Fig. 3. For male participants, a high-fat diet was significantly associated with higher odds of total femur (OR: 1.362, 95%CI: 1.124–1.652) and trochanter (OR: 1.396, 95%CI: 1.148–1.697) osteopenia or osteoporosis after adjustment for relevant covariates. However, there was no significant correlation with the prevalence of intertrochanteric (OR: 1.42, 95%CI: 0.935–1.395) osteopenia or osteoporosis. In addition, it should be noted that a high-fat diet was negatively associated with the occurrence of osteopenia or osteoporosis in femoral neck (OR: 0.65, 95%CI: 0.553–0.764). For female participants, a high-fat diet was only an independent factor for an increased prevalence intertrochanteric (OR: 1.395, 95%CI: 1.108–1.756) osteopenia or osteoporosis after adjustment for confounders. The association between a high-fat diet and osteopenia or osteoporosis of total femur (OR: 0.759, 95%CI: 0.613–0.94) and femoral neck (OR: 0.524, 95%CI: 0.418–0.655) was inverse. There was no significant association between high-fat diet and trochanter (OR: 0.942, 95%CI: 0.767–1.156) osteopenia or osteoporosis.

To further evaluate the effects of a high-fat diet on osteopenia or osteoporosis, we performed a subgroup analysis of high-fat intake at four different levels (Table 2). Among the male participants, the highest fat intake levels were only significantly and negatively associated with femoral neck (OR: 0.216, 95%CI: 0.154–0.304) osteopenia or osteoporosis when compared to normal fat intake. There was no significant association with osteopenia or osteoporosis in the total femur (OR: 1.177, 95%CI: 0.696–1.99), trochanter (OR: 1.192, 95%CI: 0.721–1.972) and intertrochanteric (OR: 1.024, 95%CI: 0.584–1.796). On the contrary, in female participants, osteopenia or osteoporosis of total femur (OR: 0.177, 95%CI: 0.096–0.324), trochanter (OR: 0.347, 95%CI: 0.195–0.62) and intertrochanteric (OR: 0.382, 95%CI: 0.217–0.671) were significantly and negatively associated with the highest fat intake when compared to a normal-fat diet, with the exception of femoral neck (OR: 0.865, 95%CI: 0.505–1.481) osteopenia or osteoporosis, which was not significantly different. Therefore, in both sexes, higher levels of fat intake were found to not increase the risk of osteopenia or osteoporosis.
Discussion

The main findings of this study, which was conducted based on large sample data of a representative American population aged 50 and over, were as follows: 1) In both sexes, although the high-fat diet was independently associated with DXA-based diagnosis of osteopenia or osteoporosis, the positive and negative effects of a high-fat diet on odds of osteopenia or osteoporosis depended on the femoral sites. 2) In this study, higher levels of fat intake did not increase the subject's risk of osteopenia or osteoporosis.

In human studies, a high-fat diet could exacerbate the decrease of bone mineral density, along with a higher risk of osteopenia or osteoporosis. A previous study using NHANES III data showed a negative correlation between BMD and saturated fat intake, suggesting that a diet rich in saturated fatty acids may increase the odds of bone disease[27]. High dietary fat intake in Korean men may lead to poor bone strength, while women have negative effects regardless of their fat intake[15]. Our findings on the negative effects of a high-fat diet on osteopenia or osteoporosis, such as an increased risk for total femur and trochanter osteopenia or osteoporosis in men, were consistent with those previously analyses. Numerous literature data had also indicated that western dietary pattern with high saturated fatty acid content was commonly associated with the lower BMD in both sexes[11, 18, 28–30]. Nevertheless, the influence of a high-fat diet on bone health is bidirectional. Researches have shown that high-fat diet has positive effects on BMD[12, 13, 16–18]. Minematsu A et al found that high fat intake could contribute to increase bone mass of old rats[31]. A high-fat/high-sucrose diet improved whole body bone mass, BMD and bone metabolism in male rats[32]. The result of our study also demonstrated that a high-fat diet was not considered to be a negative effect on BMD and the incidence of osteopenia or osteoporosis. A similar study also revealed fat intake appeared to be positively correlated with BMD[10].

Moreover, BMD is well known to vary according to various factors, including age, the loading environment, bone microstructures and ossification processes of bone specific sites, and the degree of variation is site specific in the same individual[33]. Our results showed that positive and negative effects of a high-fat diet on osteopenia or osteoporosis in humans may depend on idiographic sites. Animal studies have shown that the potential mechanism of lowering of BMD and bone microstructure by high-fat diet might be that high-fat diet affects the imbalance of intestinal flora, deterioration of intestinal barrier, inflammation, oxidative stress and the accumulation of bone marrow adipose tissue (MAT)[13]. The role of marrow adipose tissue (MAT) on bone health is complex[34]. MAT is a vital endocrine organ to regulate systemic metabolism, and the increased MAT is closely related to osteopenia or osteoporosis[35–37]. Meanwhile, Expansion of MAT in response to high fat diet had a detrimental impact on bones, which can reduce bone mineral density[14, 18, 38]. The effect of a high-fat diet on rodent bone health is influenced by three major factors, including age/duration of intervention, dietary composition and secondary occurrence of metabolic complications[12]. Studies have also reported that the obvious beneficial effects of a high-fat diet on bones are mainly due to the increase in bone mass caused by diet-induced obesity[17, 18]. Hence, we hypothesized that the different effects of a high-fat diet on BMD and the prevalence of osteopenia or osteoporosis in the present study may be attributed to diverse features of...
anatomical location of femur. Of course, this speculation needs further examination or experiment to verify.

There are some limitations in this study. Although subjects' dietary recall records ensured that the amount of food consumed appeared to be the same as usual, there was a false positive bias and uncertainty in the recall, and therefore there were limitations regarding the measurement of long-term dietary intake. Then, the cross-sectional design does not allow the conclusions of cause-effect relationships to be drawn. Last, the measurement results based on DXA examination cannot reflect the microstructures of bones and the characteristics of specific parts of bones.

Conclusions

In conclusion, the effects of a high-fat diet as a separate contribution to bone mineral density and the incidence of osteopenia or osteoporosis were biphasic with both positive and negative effects that varied by femoral sites and were not gender-related. In addition, higher levels of dietary fat intake did not increase the odds of osteopenia or osteoporosis.

Declarations

Ethical Approval and consent to participate

Given that the datasets in all analyses were fully de-identified, this study was approved by the Institutional Review Board.

Consent for publication

Not applicable.

Availability of data and materials

The datasets presented in this study can be found in an online repository: NHANES 2017-2018 Available at:


Competing interests

The authors declared that they have no competing interests.

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None.

Authors’ contributions
Na Li takes responsibility for the content of the manuscript, including the data and analysis. Na Li and Qing He contributed substantially to the study design and the writing of the manuscript. Na Li, Yuan Cheng, Tao Jin and Xiong Zhu collected data and performed the data analysis and interpretation.

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Tables

Tables 1 and 2 are not available with this version

Figures
Figure 1

Flow diagram of the study participants.
Figure 2

Multivariable logistic regression model assessing the association of high-fat diet and the odds of osteopenia or osteoporosis in the male population.

(A) Intertrochanteric Osteopenia or Osteoporosis; (B) Trochanter Osteopenia or Osteoporosis; (C) Total Femur Osteopenia or Osteoporosis; (D) Femoral Neck Osteopenia or Osteoporosis.
Figure 3

Multivariable logistic regression model assessing the association of high-fat diet and the odds of osteopenia or osteoporosis in the female population.

(A) Intertrochanteric Osteopenia or Osteoporosis; (B) Trochanter Osteopenia or Osteoporosis; (C) Total Femur Osteopenia or Osteoporosis; (D) Femoral Neck Osteopenia or Osteoporosis.